asthma. Not surprisingly, PM pollution is associated with the increased prevalence of the condition in children. A study of asthmatic African-American children in Los Angeles found an association between reported asthma symptoms and ambient PM concentrations.[20] Not only can particulate matter from diesel exhaust trigger asthma attacks in people who already have asthma, but also recent scientific studies indicate that diesel may affect lung function and even cause asthma in previously healthy people.[21,22] For example, children living near busy diesel trucking routes have decreased lung function by comparison with children living near roads with mostly automobile traffic.[23] A survey of nearly 40,000 children in Italy found that children living on streets with heavy truck traffic were 60 to 90 percent more likely to have wheezing, phlegm, bronchitis, and pneumonia.[24] A German study of nearly 4,000 adolescent students found that those living on streets with constant truck traffic

Children raised in heavily polluted areas have reduced lung capacity, prematurely aged lungs, and an increased risk of bronchitis and asthma than do peers living in less urbanized areas.

AIR POLLUTION RISKS TO PREGNANT WOMEN AND CHILDREN

Children are at particular risk from air pollution, in part because their lungs are still developing and their airways are narrower than those of adults, and in part because they often play outdoors during the day and thus may have greater exposure. Children raised in heavily polluted areas have reduced lung capacity, prematurely aged lungs, and an increased risk of bronchitis and asthma than do peers living in less urbanized areas.

In a study comparing air pollution in six U.S. cities and the respiratory health of individuals living in those cities, the frequencies of cough, bronchitis, and lower respiratory illness in preadolescent children were significantly associated with increased levels of acidic fine particles from pollution. Illness and symptom rates in the community with the highest air pollution concentrations were twice those in the community with the lowest concentrations. In addition, some studies have suggested that children with preexisting respiratory conditions—wheezing and asthma, for example—are at an even greater risk of developing symptoms from exposure to air pollutants. Furthermore, new research shows that asthmatic children experience a significant increase in wheezing and chest tightness at ozone levels significantly below federal standards.

Recent research also indicates that cancer-causing chemicals from diesel exhaust can cross the placenta in humans, thus subjecting developing fetuses to the effects of pollution to which mothers are exposed. Although fetal exposures to these chemicals are one-tenth those of their mothers, genetic damage is detectable in newborn blood samples at levels significantly higher than in maternal blood. These indications of DNA damage demonstrate that the fetus may be significantly more susceptible than the mother to these chemicals.

Sources: DW Dockery, et al.: "Effects of inhalable particles on respiratory health of children," *Am Rev Respir Dis* 139: 587–594, 1989. J Peters, et al. "A study of twelve southern California communities with differing levels and types of air pollution. II. Effects on pulmonary function." *Am J. Respir, Crit Care Med* 159: 768–775, 1999. JH Ware: "Effects of ambient sulfur oxides and suspended particles on respiratory health of preadolescent children," *Am Rev Resp Dis* 133:834–842, 1986. JA Pope, Dockery DW: "Acute health effects of PM_{10} pollution on symptomatic and asymptomatic children." *Am Rev Respir Dis* 145: 1123–1128, 1992. KM Mortimer, et al.: "The effect of air pollution on inner-city children with asthma." *Eur Respir J* 19:699–705, 2002. JF Gent, et al. "Association of low-level ozone and fine particles with respiratory symptoms in children with asthma," *Journal of the American Medical Association*, 290 (14): 1859–1867, 2003. RM Whyatt, et al.: "Biomarkers of polycyclic aromatic hydrocarbon-DNA damage and cigarette smoke exposures in paired maternal and newborn blood samples as a measure of differential susceptibility." *Cancer Epidemiol Biomarkers Perv* 10: 581–588, 2001.

were 71 percent more likely to have nasal allergies, and more than twice as likely to report wheezing.[25]

Rates of Hospitalization and Death Increase from PM Pollution A number of research studies have found that even short-term increases in PM pollution can have lethal effects. Studies in six U.S. cities and in Canada showed that daily increases in PM are associated with increased deaths in the days immediately following.[26] The deaths were among individuals with heart and lung disease—those most susceptible to the noxious effects of PM pollution. An examination of data from Detroit, Los Angeles, and Toronto led researchers to conclude that when PM pollution rises, hospitalizations for heart failure, chronic obstructive lung disease, and pneumonia in the elderly also rise.[27] Separately, a major study of 1.2 million adults followed for two decades found that exposure to PM pollution was linked with an 8 percent increase in lung cancer death for every 10 microgram per cubic meter increase of particulate matter in the air.[28]

A major study of 1.2 million adults followed for two decades found that exposure to PM pollution was linked with an 8 percent increase in lung cancer death.

Adverse Health Effects from Volatile Organic Compounds

Not only are volatile organic compounds inherently toxic, but also when they evaporate into the air, they can react with other pollutants to form ozone smog. Common VOCs produced by diesel engines include benzene, 1,3-butadiene, formaldehyde, and toluene, each of which poses significant health risks.[29] Benzene and butadiene are known to cause cancer in humans. Formaldehyde is very irritating to the airways and is a probable carcinogen. Toluene has been associated with birth defects and miscarriages and is listed as "known to the state of California to cause birth defects or reproductive harm."[30] Other VOCs emitted by vehicles have also been linked to cancer, reproductive harm, asthma, or neurological disorders.[31]

Adverse Health Effects from Nitrogen Oxides

Nitrogen oxides include a large family of chemicals, including nitrogen dioxide, nitric acid, nitrous oxide, nitrates, and other related compounds. They can cause a wide variety of health problems, including respiratory distress, and environmental problems, including smog. In addition, NO_x also reacts with ammonia, water vapor, and air pollutants to form other chemicals, some of which can cause cell mutations and even cancer.

A number of studies have found that NO_x can have a toxic effect on the airways, leading to inflammation and asthmatic reactions.[32] In fact, people with allergies or asthma have far stronger reactions to such common allergens as pollen when they are also exposed to NO_x.[33] A European study of nearly 850 seven-year-old children living in nonurban communities found that where the nitrogen dioxide levels are consistently high, such as near major roads or ports, children were up to eight times as likely to be diagnosed with asthma.[34] In addition, children who already have asthma are more likely to cough, wheeze, and suffer from decreased pulmonary function when ambient levels of NO_x in the air are high.[35] Scientists have also found some evidence that nitrogen dioxide increases the risk of asthma attacks following respiratory infections. A yearlong study of 114 asthmatic children found that the combination of moderately elevated outdoor nitrogen dioxide levels and a respiratory infection doubled the risk of an asthma attack following either an infection or elevated NO_x levels alone.[36]

Decreased Lung Function from Ozone (Smog)

The layer of brown hazy smog found over most urban areas in the United States is not just an eyesore, it is a source of serious illnesses. Ozone, also known as smog, is a reactive gas produced when VOCs and NO_x interact with sunlight and split apart oxygen molecules in the air. Ozone is extremely irritating to the airways and the lungs, causing serious damage to the delicate cells lining the airways. It contributes to decreased lung function, increased respiratory symptoms, asthma, emergency room visits, and hospital admissions.[37] Ozone can also make people more susceptible to respiratory infections.[38] Ozone can cause irreversible changes in lung structure, eventually leading to chronic respiratory illnesses, such as emphysema and chronic bronchitis.[39] Those particularly at risk from ozone include children, people with respiratory disease, asthmatics, and people who exercise outdoors.

Children in Southern California living in areas with high ozone levels and playing outdoor sports had three times the risk of developing asthma as children who played outdoor sports in lower ozone areas.

Among the thousands of published studies on the health effects of ozone are recent research studies identifying a link between long-term ozone concentrations in air and new-onset asthma.[40] Children in Southern California living in areas with high ozone levels and playing outdoor sports had three times the risk of developing asthma as children who played outdoor sports in lower-ozone areas.[41] Asthmatic children experience a significant increase in wheezing and chest tightness at ozone levels significantly below federal standards, according to another new study.[42] A recent study in Toronto reported a relationship between short-term elevations in ozone concentrations and hospital admissions for respiratory symptoms in children younger than two years old.[43] Increased respiratory disease serious enough to cause school absences has been associated with ozone concentrations in studies from Nevada and Southern California.[44]

Short-term ozone exposure may also be a contributing factor to premature death. The inflammation caused by ozone may make elderly and other sensitive individuals more susceptible to the adverse effects of other air pollutants, such as particulate matter.[45] Even short-term exposures to high ozone levels are unhealthy for this most susceptible group of people. A study in eight European cities (London, Athens, Barcelona, Paris, Amsterdam, Basel, Geneva, and Zurich) found a correlation between specific times of death and peak ozone levels, as measured on an hourly basis.[46]

Adverse Health Effects from Sulfur Oxides

Burning sulfur-containing fuels, such as diesel and high-sulfur marine fuels, produces sulfur oxides (SO_x), including sulfur dioxide and a range of related chemical air pollutants. SO_x react with water vapor in the air to create compounds that irritate the airways, sometimes causing discomfort and coughing in healthy people and often causing severe respiratory symptoms in asthmatics.[47] One study found that when asthmatics were exposed under controlled conditions to levels of sulfur dioxide similar to those found near pollution sources—ports, for example—

lung function dropped by an average of 25 to 30 percent.[48] In addition, several studies indicate that the combination of SO_x and NO_x in the air is particularly noxious because the compounds appear to act together to increase allergic responses to such common allergens as pollen and dust mites.[49]

THE SOURCES OF AIR POLLUTION AT PORTS

Many major ports, including the ports of Los Angeles and Long Beach, operate virtually next door to residential neighborhoods, schools, and playgrounds. These nearby communities face extraordinarily high pollution-related health risks resulting from their close proximity to the ports.

The major port-related sources of diesel pollution are shown in Figure 1-1. In California, container ports account for roughly 6 percent of diesel particulate pollution.[50] This significant percentage is growing every year, in part because air emissions from port-related sources remain largely unregulated. Ships, container-handling equipment, and heavy trucks account for 95 percent of total NO_x and 98 percent of total diesel PM emissions.[51]

Marine Vessels

For fossil fuel sources worldwide, marine vessels emit 14 percent of the nitrogen oxides, 5 percent of the sulfur oxides, and 2 percent of the carbon dioxide.[52] In 2000, commercial marine vessels accounted for roughly 7 percent of NO_x and 6 percent of PM emissions from all mobile sources in the United States.[53] Because these vessels are poorly regulated, their share of polluting emissions is expected to double by 2020.[54] In fact, commercial diesel ships are expected to account for one-fifth of all diesel particulate generated in 2020, making them the second largest source of this toxic soot.

CONTAINER PORTS VERSUS CARS

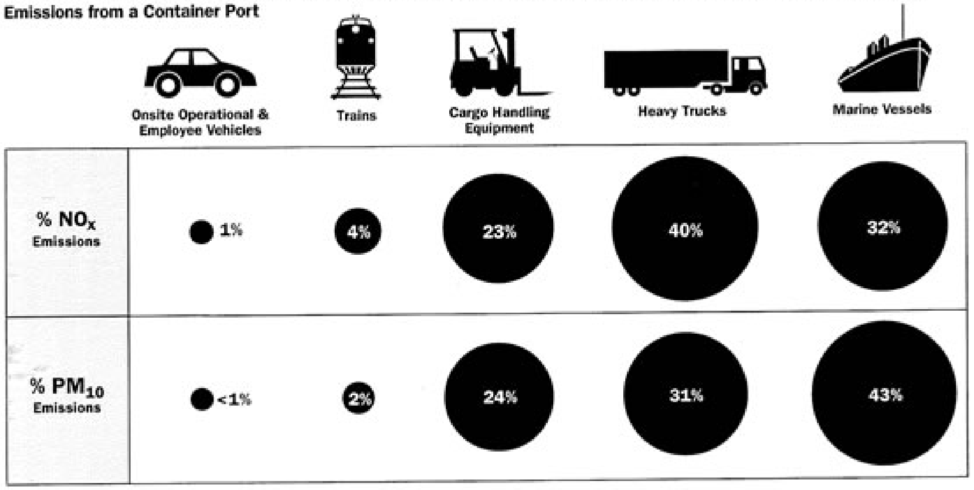
To place port pollution in context, during 2000, the 10 largest container ports combined polluted more than the following number of cars for these major pollutants:

More than **80 thousand cars** worth of CO
More than **182 thousand cars** worth of VOC
More than **3.2 million cars** worth of NO_x
More than **8.1 million cars** worth of PM_{10}
More than **18.5 million cars** worth of SO_x

In 2000, container vessels calling at the ten largest U.S. ports polluted the air with more sulfur dioxide than all of the cars in the states of New York, New Jersey, and Connecticut combined. Container-related heavy-truck traffic polluted the air with more NO_x within port terminal areas alone than the NO_x from each car in the state of Kansas. And passenger vehicle traffic in South Carolina polluted less particulate matter than all of the container-handling equipment at the ten largest ports.

Sources: Federal Highway Administration; EPA National Emission Trends 2000 Inventory; environmental impact reports and related emission inventories from Ports of Los Angeles, Long Beach, Houston, and Oakland; and Seaports of the Americas.

FIGURE 1-1
Average Contributions of Various Port-Related Sources to Total Nitrogen Oxides (NO_x) and Particulate Matter (PM_{10}) Emissions from a Container Port



Sources: *Marine Vessels Emissions Inventory* (Ports of Los Angeles and Long Beach), ARCADIS, Sept. 1999, Appendix G, pg. 6, 2000 forecast—Marine Emissions Inventory and Table 4-2, page 4-2. *The New York, Northern New Jersey, Long Island Nonattainment Area Commercial Marine Vessel Emissions Inventory, Volume 1—Report*, prepared by Starcrest Consulting Group, LLC, for the Port Authority of NY & NJ, April 2003. *The Port of New York and New Jersey Emissions Inventory for Cargo Handling Equipment, Automarine Terminal Vehicles, and Associated Locomotives*, prepared by Starcrest Consulting Group, LLC, for the Port Authority of NY & NJ, June 2003. *Port of Houston, Final Environmental Impact Statement*, Bayport Ship Channel Container/Cruise Terminal, Appendix 3, May 2003. *Port of Oakland Final Environmental Impact Report*, Berths 55-58 Project, SCH. NO. 97102076, Appendix C: Emissions Calculations, December 1998.

Container ship traffic to and from the United States doubled between 1990 and 2001, and the rate of increase is expected to continue.[55] Of the 58,000 calls made by large ships at U.S. ports in 2000, almost 30 percent were made by container ships.[56] Container ships calling in the United States weigh on average almost 38,000 tons.[57] The new generation of container ships, dubbed post-Panamax because they cannot fit through the Panama Canal, are longer than three and a half football fields, or longer than the Eiffel Tower is tall. These vessels produce great quantities of polluting emissions, both because of the power required to propel their enormous mass and because they tend to run on the dirtiest grade of diesel fuel available, called "bunker" or "residual" fuel.[58]

Other vessels contributing to pollution at U.S. ports include tanker and cruise ships and such harbor craft as tugboats and towboats. All are large consumers of diesel fuel. In the Los Angeles area, oceangoing ships, harbor tugs, and commercial boats emit twice as many smog-forming emissions as all of the area's power plants combined.[59]

Cargo-Handling Equipment

Every day, thousands of railcar-size container units arrive by ship at U.S. ports, laden with a broad range of imported products. Once on dry land, the containers are then transferred to rail and truck and carried to market. These containers, and the ships that carry them, require special cargo-handling equipment at ports. Primarily powered by diesel fuel, the equipment is used to load and unload containers from ships, locomotives, and trucks, as well as to shuttle those containers around container yards for storage. Cargo-handling equipment includes large gantry cranes used to load and unload ships, yard trucks that shuttle containers, and various others called top-picks, side-picks, straddle carriers, and forklifts. Regulation of off-road diesel equipment lags a few decades behind the regulation of on-road diesel trucks and buses.[60] In fact, emission standards for heavy diesel equipment were not established until 1996 and are much weaker than on-road standards.[61] Indeed, by 2007, new heavy diesel equipment will create 15 times more PM and NO_x pollution than new highway trucks or buses.[62] The Environmental Protection Agency's (EPA) recently adopted off-road diesel rule will significantly strengthen standards for off-road equipment. However, the rule will be phased in from 2008 to as late as 2015 and will cover only new equipment.

Container operations have considerably larger pollution effects than other types of cargo-handling operations at ports. At the Port of Houston, for example, only 42 percent of equipment is associated with container operations, but that equipment accounts for approximately 70 percent of NO_x emissions from on-site port activities.[63] The significant emissions from container-handling equipment is problematic at ports such as Los Angeles and Long Beach, where more than 90 percent of the roughly 2,000 pieces of equipment are associated with container operations.

Heavy Trucks Transporting Cargo to and from Ports

The majority of large trucks that service ports, dropping off and picking up containers, tend to be older and more polluting than long-haul trucks.[64] Moreover, virtually all run on diesel fuel. Not only do the trucks add to existing traffic, but also they often form bottlenecks at terminal entrance gates, idling for long periods and contributing even more pollution.[65] A single port complex can receive thousands of trucks entering and leaving on a typical business day.[66]

Locomotives

More than three-quarters of all train traffic in the United States transports containers, and most of these trains are traveling to or from marine ports.[67] Overall, locomotives are a more environmentally efficient way to transport goods than trucks (see "Rail Versus Road," page 52), but train engines are less heavily regulated—and therefore more polluting—than on-road truck engines.[68] Switching locomotives, used to connect containers on flatbed railcars, are commonly so old as to predate any emission standards. Known as the dirtiest of all rail

Thousands of trucks idle in long lines outside port gates, emitting tons of harmful exhaust.

JANET GUNTER

engines, they are the workhorses of the rail yards located in or near ports, operating nearly nonstop.

Other significant sources of air pollution at ports include cars, light- and medium-duty trucks, personnel vehicles, recreational marine vessels, diesel-powered refrigeration units (reefers), various generators for power, petroleum, and chemical handling and storage equipment, maintenance and repair operations, and a variety of commercial and industrial enterprises commonly colocated at ports. Combined, all of these sources cause a major portion of regional air pollution, leading to the serious health effects described earlier. See "Container Ports Versus Cars," page 7 for a comparison of the pollution levels from the 10 largest U.S. ports compared to the amount of pollution from automobile traffic.

Control measures that can be employed to address all of the major air pollution sources outlined here are detailed in Chapter 2. Marine ports, however, affect many other aspects of the environment and public health and quality of life beyond air quality. While the focus of this report is on air pollution from ports, other important issues are briefly described next.

The new generation of container ships, dubbed post-Panamax because they cannot fit through the Panama Canal, are longer than three and a half football fields, or longer than the Eiffel Tower is tall.

MARINE PORT ACTIVITIES DEGRADE WATER QUALITY

Waste from ships, either dumped directly or leached into water, can cause significant damage to water quality, and subsequently to marine life and ecosystems and human health. These effects may include bacterial and viral contamination of commercial fish and shellfish, depletion of oxygen in water, and bioaccumulation of certain toxins in fish.[69]

Oily bilge water is one major pollutant from ships. Water collected at the bottom of the hull of a ship, known as the bilge, is often contaminated by leaking oil from machinery. This bilge water must be emptied periodically to maintain ship stability and to prevent the accumulation of hazardous vapors. This oily wastewater, combined with other ship wastes, including sewage and wastewater from other on-board uses, is a serious threat to marine life.[70]

Other pollutants from ships are the antifouling additives used in the paint on ships to prevent the growth of barnacles and other marine organisms on ship surfaces. Some of these additives contain tributyltin (TBT), a toxic chemical that can leach into water.[71] Once in the water, TBT is absorbed by marine life. In fact, TBT bioaccumulates, meaning that it is not simply released by marine life but rather builds up in the body and is taken in by predators.[72] Not surprisingly, researchers have found TBT in bottleneck dolphins and bluefin tuna. TBT can cause masculinization of female snails through disruption of endocrine systems.[73] It has also been shown to cause oyster larvae mortality and deformations in oyster shells.[74] In shipyard workers, TBT has been linked to skin irritation, stomach aches, colds, influenza, and such neurological symptoms as headaches, fatigue, and dizziness.[75] While toxic antifouling additives are slowly being phased out of use, these toxic pollutants persist in the marine environment.

Environmentally safe alternatives to TBT are widely available. They include copper-based and tin-free antifouling paints, nonstick coatings that provide a slippery surface on which organisms cannot attach, prickly coatings that also prevent attachment, regular cleaning of the hull, natural biocides that imitate corals' and sponges' antifouling secretions, and electrical current.[76]

Stormwater Runoff

Rain and other forms of precipitation are naturally occurring events that are not in and of themselves polluting. But when stormwater travels as runoff across paved surfaces, it can accumulate deposits of air pollution, automotive fluids, sediments, nutrients, pesticides, metals, and other pollutants. In fact, urban stormwater runoff from all sources, including marine ports, is the largest source of impairment in U.S. coastal waters and the second largest source of water pollution in U.S. estuaries.[77] The high quantities of pollution carried by stormwater, as well as the increased volume, velocity, and temperature of the water as it runs off paved surfaces can lead to dramatic changes in hydrology and water quality.

Virtually all of the land at a port terminal is paved and therefore impervious to water. Scientists have repeatedly demonstrated a correlation between such impervious surfaces and stormwater pollution. For example, a one-acre parking lot produces 16 times the runoff of an undeveloped meadow.[78] Numerous studies have documented the adverse environmental effects from increases in impervious surfaces in a given area, including flooding, habitat loss, water quality decline, and reduced diversity of aquatic life.[79]

A one-acre parking lot produces 16 times the runoff of an undeveloped meadow.

Eutrophication

If waterbodies are overloaded with nitrogen, then algae and plankton can rapidly increase in numbers, forming blooms—sometimes called red or brown tides. This process, called eutrophication, has been identified by the National Research Council as the most serious pollution problem facing estuaries in the United States.[80] The EPA estimates that NO_x air pollution contributes between 12 and 44 percent of total nitrogen water pollution, making it the leading cause of eutrophication.[81] The resulting algal blooms use up the oxygen in water, killing large numbers of fish and shellfish. Such blooms and resulting fish kills have been seen off the New England coast and in other areas of the United States.[82] As noted earlier, ports are major sources of NO_x and thus major contributors to eutrophication.

Oil Spills

Oil spills continue to be a large marine pollution problem. In the year 2000, 8,354 oil spills were reported in U.S. waters, accounting for more than 1.4 million gallons of spilled oil. The majority of these spills have occurred in internal and headlands waters, including the harbors and waterways upon which ports rely.[83]

A large share of oil contamination is the result of "chronic" pollution from such sources as port runoff, unloading and loading of oil tankers, and removal of bilge water, and it leads to three times as much oil pollution as do tanker accidents.[84] However, large, "catastrophic" spills also have a significant impact. One such spill in 2000, resulting from the overfilling of a tank barge, dumped 80,000 gallons of oil into the Houston Ship Channel.[85] In 2002, in Charleston, a tear in a ship spilled

12,500 gallons of oil into the Cooper River, causing much long-term ecological damage and accounting for millions of dollars in cleanup costs. Another spill of 500 gallons in Charleston's Wando Welch Terminal in February 2003 fueled concern that such spills are becoming more frequent because of the port's growth.[86]

Oil spills can harm both ecosystems and people's health, as the *Exxon Valdez* spill showed when it caused massive wildlife die-offs.[87] Oil can diminish animals' insulation by sticking to fur or feathers and can even poison animals that ingest or inhale its many toxins. These toxins also cause long-term damage to the lungs, liver, and kidneys, as well as to the digestive, reproductive, and central nervous systems. Oil may even pass from bird feathers through the pores of eggs a bird is guarding, killing or severely damaging developing chicks still in the shell.[88] Certain contaminants in oil may bioaccumulate, causing health consequences at levels higher up in the food chain.[89] In fact, oil-contaminated seafood poses a risk to humans who eat it.[90]

Each year, dredging of U.S. waterways and harbors produces more than 300 million cubic yards of sediment—enough to cover a four-lane highway with a 20-foot mound from New York City to Los Angeles.

Dredging

Ports are routinely dredged to remove sediment that builds up in ship channels from erosion and silt deposition, as well as to create new channels and deepen existing ones. Each year, more than 300 million cubic yards of sediment in waterways and harbors is dredged to allow ships to pass through.[91] The total amount of these annual "dredge spoils" is enough to cover a four-lane highway with a 20-foot mound from New York City to Los Angeles.[92] Much of this sediment is disposed of in open water or near shore, but some may also be used as fill in various land-based projects.

About 5 to 10 percent of dredged sediment is contaminated with toxics, including polychlorinated biphenyls (PCBs), mercury and other heavy metals, polycyclic aromatic VOCs (PAHs), and pesticides, all of which can cause water contamination and complicate sediment disposal.[93]

Dredging may increase water turbidity (cloudiness), harm habitat, and disturb or kill threatened and endangered species. It may also risk stirring up and releasing buried contaminants. Dredging performed by the Port of Miami in the early 1990s raised concerns over the destruction of seagrasses and the harbor's rocky seabeds, or "hardbottom." Post-dredging hardbottom restoration was fairly effective, but measures introduced to mitigate the loss of seagrass were far less so, successfully replacing only 10 percent of lost seagrass and robbing manatees and sea turtles of an important food source and habitat.[94,95]

The dangers of dredging have taken on even greater significance in recent years, with the growing popularity of post-Panamax vessels, which require channel depths of 45 to 50 feet.[96] In a scramble to remain competitive, many ports are being redredged to deepen or widen their shipping channels. The ports of Charleston, Los Angeles, Long Beach, Miami, Savannah, New York/New Jersey, and Houston are all involved in such projects, creating millions of extra cubic yards of dredge material that will need to be disposed of somewhere.[97]

Alternative methods of disposal of dredged sediment are available. They include construction and industrial uses, fill material for parking lots and roads, landfill cover, shoreline erosion control, artificial reef material, and wetland creation and restoration. The Port of Houston has built marshes and a wildlife habitat with its ship channel sediment, more than 16 million cubic yards of which has been removed since 1998. Over the course of the ongoing project, about 4,250 acres of intertidal salt marsh and a six-acre bird nesting and habitat island are being constructed, and 40 acres of an eroded island are being restored in the largest effort of its kind in the country.[98] The sediment used for the project was deemed nontoxic by a coalition of government agencies called the Beneficial Uses Group. Many organizations are advocating for the beneficial reuse of dredge material, as long as it is not contaminated.[99] A number of groups are exploring further alternative methods for disposal of contaminated dredge.[100]

Specific Threats to Marine Life

The EPA estimates that only half of the continental United States' original wetlands remain; millions of acres have been lost to development. From 1986 to 1997, some 58,500 acres of wetland were lost *each year*, and today, the remaining wetlands are home to one-third of the nation's threatened or endangered species. Because many ports are located either on former wetland sites or near remaining wetlands, they pose grave dangers to sensitive ecosystems and the surrounding areas. The combined effects of dredging, drainage, fill, runoff, and air and water pollutants include disruption of bird migration patterns, loss of biodiversity, increased flooding, chemical contamination of soil and marine life, loss of recreational opportunities, and erosion.[101]

The EPA estimates that only half of the continental United States' original wetlands remain; millions of acres have been lost to development, including development of port terminals.

Water sedimentation from erosion and dredging may also cause irreversible damage to other important centers of biodiversity such as seagrass beds. In addition, toxic contaminants in sediment or runoff may affect commercial fish populations and even make these fish unsafe for human consumption. Three-quarters of all commercial fish are caught in the estuaries in which ports are located.[102] Projects to mitigate this loss of habitat are cropping up throughout the country. As noted earlier, one such effort has been undertaken at the Port of Houston.

Collisions involving boats and marine mammals also contribute to marine mortality. Since 1995, along the East Coast, eight right whales, a species in danger of extinction, have been killed by collisions with ships. These whales must share the coastal waters they need for migration routes with the ships that travel to and from bustling East Coast ports.[103] Manatees also die from collisions with ships or from being crushed beneath barges or between docks and vessels in the shallow estuaries, bays, and canals along which ports are located.[104]

Expansive wharves built on piles can block sunlight from reaching aquatic plants upon which marine wildlife rely for survival. For example, the manatee in Florida, salmon, Dungeness crab, and Pacific herring in Puget Sound suffer from such loss of habitat.[105,106]

Exposure to debris, including plastic bags, netting, and plastic pellets, results in thousands of wildlife deaths each year, through starvation, exhaustion, or ingestion of toxics often found in plastics.[107] Plastic pellets, the raw material for plastic goods, have been found polluting oceans all over the world, as well as 13 of 14 U.S. harbors tested in an EPA study. The pellets can be spilled directly into the ocean from shipping containers or can travel via stormwater discharge. They are known to be ingested by one-quarter of all seabird species and have been found to account for 71 percent of all plastic ingested by seabirds.[108,109] In the Houston Ship Channel alone, 250,000 pellets were found in a single sample during a 1992 study.[110] The effects on seabirds include malnutrition (since they have been found to mistake pellets for food), stomach ulcers, and accumulation of PCBs in the birds' systems.[111] These pellets can also cause problems higher up in the food chain because they can store and transport toxic chemicals in addition to PCBs, including DDE (a breakdown product of DDT) and nonylphenols.[112]

Roughly 10,000 of the 100 million containers shipped annually fall overboard.[113] As containers are stacked ever taller and wider, the odds of spillage increase, which is particularly alarming given that almost one-third of all cargo is hazardous material.[114]

Ballast Water

Ballast water taken in or discharged by large ships to maintain balance is responsible for the transport of thousands of marine species into foreign habitats worldwide. These invasive species often prey upon native species, or compete for resources with them—thus posing hazards to native species and ecosystems and threatening biodiversity and human health.[115] For example, ballast water from cargo ships has been implicated in transporting a South American strain of cholera to the Gulf of Mexico, leading to fish and shellfish contamination.[116] Ballast water itself is also responsible for the introduction of "red tide" algae to the waters of several countries, contaminating shellfish and threatening human health.[117,118] The 3 billion to 5 billion tons of ballast water moved by ships annually, including the 80 million tons discharged into U.S. waters, is only loosely regulated.[119,120]

Roughly 10,000 of the 100 million containers shipped annually fall overboard.

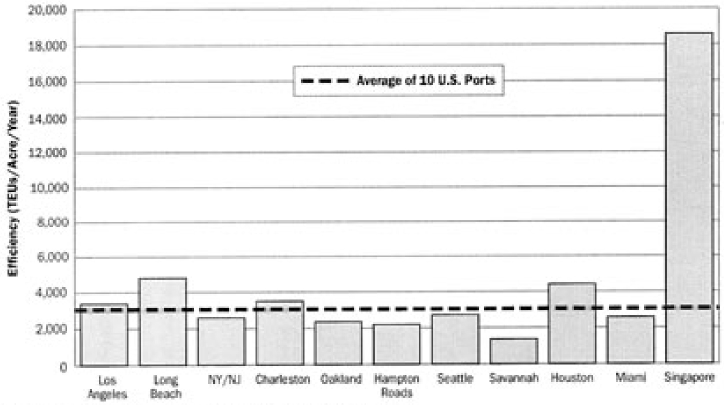
MARINE PORT LAND USE CAN ADVERSELY AFFECT NEIGHBORING COMMUNITIES

As noted, the highly industrialized operations at ports are often in close proximity to residential areas, creating a number of hazards and nuisances for nearby communities. Ports have several available options to avoid developing new terminals near residential areas. They can develop property previously used in an industrial capacity, or they can increase the land use efficiency of existing terminals. The land use patterns at U.S. ports suggest much room for effiency improvements. Of the ten largest U.S. ports, even those that are most efficient in terms of land use—Long Beach and Houston—are only one-fourth as efficient as the Port of Singapore, a model of land use efficiency. The ports of Savannah and Hampton Roads exhibit the least efficient land use, as shown in Figure 1-2. Details of this comparison can be found in Appendix A.

Brownfields

Brownfields are tracts of land developed for industrial purposes, polluted or perceived to be polluted, and then abandoned.[121] The potential costs of cleaning up brownfield sites makes them unappealing to companies looking to locate or

FIGURE 1-2
Land Use Efficiency at 10 U.S. Ports Compared to the Port of Singapore



Note: Data used to prepare this graph are explained in Appendix A.

expand. As a result, new industrial operations are often sited on pristine, undeveloped greenfield land, often leading to a loss of habitat and wildlife, increases in air and water pollution, and urbanization of open space valuable for recreation and aesthetic qualities.[122]

However, developing brownfields offers many advantages to business, communities, and the environment. Businesses benefit from locating on sites near existing transportation infrastructure and with a utility infrastructure already in place, while cleaning up contamination that poses a danger to both the community and the environment.[123] Several ports, including the ports of Seattle and Long Beach, have demonstrated the feasibility of brownfield redevelopment on their properties.[124,125]

Noise Pollution

With machines, trucks, and ships operating 24 hours a day, and pile driving and blasting from channel maintenance and expansion, ports can be loud. The noise pollution from port activities, in addition to being annoying, can have serious negative health effects. Noise pollution has been linked to hearing impairment, high blood pressure, sleep deprivation, reduced performance, and even aggressive behavior.[126] Additionally, noise from ship engines may disturb marine mammal hearing and behavior patterns, as well as bird feeding and nesting sites.[127,128]

With those dangers in mind, several ports are taking steps to reduce noise pollution. The ports of Stockholm, Helsinki, Copenhagen, and Oslo are working together to reduce noise emitted from cruise ships, for example, and a new law passed in March 2003 in Valencia, Spain, calls for a reduction in noise pollution and will most likely regulate that city port's equipment and machinery.[129,130]

People of color and low-income families live next door to more polluters than any other group in the United States.

Light Pollution

Artificial lights at ports, sometimes burning 24 hours a day, can have negative effects on wildlife, including disorientation, confusion of biological rhythms that are adapted to a day/night alternation, and a general degradation of habitat quality. This pollution can cause high mortality in animal populations, particularly to birds attracted to brightly lit buildings and towers; they can circle these structures until they die of exhaustion or fly head-on into them.[131,132] At ports bordering residential neighborhoods, bright nighttime lights and the flashing lights of straddle carriers and forklifts can affect nearby residents, disrupting biological rhythms and causing stress and annoyance.[133,134]

Environmental Justice

People of color and low-income families live next door to more polluters than any other group in the United States. As a result, these communities often suffer from higher rates of illness and diminished quality of life, by comparison with residents of middle-class suburbs and affluent communities. Environmental injustices occur next to marine terminals just as they do next to other industrial and waste disposal sites such as power plants or landfills.

Communities next to marine ports are severely affected by heavy traffic and the noise and air pollution that come with it. While many communities are becoming more active on these issues, injustices continue across the country and are one of the major motivating factors to clean up industrial marine port activities.

IMPROVING PORT ENVIRONMENTAL MANAGEMENT PRACTICES

This chapter reviews cost-effective approaches to reduce air and water pollution from port-related activities. Recommended approaches are presented according to the source of port pollution (marine vessels, cargo-handling equipment, off-site trucks, and locomotives) and also as discussions about stormwater programs, construction design features, and other measures. Recommended measures for each air pollution source focus on reducing emissions from diesel engines through the "five R's":

- **Replace.** We recommend replacing the oldest, most polluting vehicles, equipment, and vessels with the cleanest available new models.
- **Repower.** Vehicles, equipment, and vessels with a significant amount of useful life left can often be repowered with cleaner new engines, simply swapping the old engine for a new one.
- **Retrofit.** In many cases, exhaust systems can be retrofitted with emission controls—also known as after-treatments—that significantly reduce exhaust emissions.
- **Refuel.** Some after-treatments require the use of cleaner fuel, which in itself can reduce emissions to some extent.
- **Reduce idling.** Opportunities abound to reduce idling, a practice that wastes millions of gallons of fuel in addition to polluting.

We recommend the following measures to maximize emission reductions from port-related diesel pollution sources:

- Clean up harbor craft, such as tugboats, through engine repower and retrofit programs. Limit idling of **oceangoing vessels and tugboats** by providing electrical power at docks and requiring ships and tugboats to "plug in" to shoreside power while at berth. Require ships to use the cleanest grade of diesel fuel possible, with a sulfur content of 15 to 2,000 parts per million (ppm). Finally, where possible, create incentives or otherwise promote the use of emission controls on oceangoing vessels.

NRDC

THE EARTH'S BEST DEFENSE

HARBORING POLLUTION

Strategies to Clean Up U.S. Ports

August 2004

ASSUMPTIONS BEHIND COST-BENEFIT DISCUSSIONS

The following four criteria were considered in the discussion of each recommendation in this section:

Available technologies. Diesel and alternative fuel and engine technologies have improved over the past few decades and continue to progress at a rapid pace. Control technologies have been further developed even during the writing of this report. We attempt in these pages to summarize only those technologies available on the market at the time of this writing.

Pollutants reduced. Emission reductions are reported based on either (a) verified or certified levels or (b) technical studies reported in trade journals or through professional organizations.

Unit costs. Because some of these measures were developed for direct application at the Port of Los Angeles, cost estimates and other criteria may differ slightly when applied to other ports. However, many of these measures are already in practice at ports around the world and are likely to be feasible elsewhere.

Cost-effectiveness. Cost-effectiveness data is presented in this report as a range to reflect variable assumptions such as the cost of certain fuels and control equipment, potential emission reductions, actual usage or mileage, and existing engine age.

► Make it a priority to retire the oldest **cargo-handling equipment**—that is, equipment that is ten or more years old. Then commit to replacing it with the cleanest available equipment and fuel choices—specifically, equipment that is designed to run on alternative fuels—where possible. Make it a priority to retrofit existing equipment that is less than ten years old so that it, too, can run on the best available control technology, such as diesel particulate filters (DPFs) with lean NO_x catalysts (LNCs) where feasible and diesel oxidation catalysts (DOCs) where DPFs are not practical. Also, switch to cleaner diesel fuels, such as low-sulfur fuel used with DPFs and diesel emulsions with DOCs.

► Create an incentive program for **off-site trucks** that encourages "fleet modernization"—the retirement of older trucks and their replacement with modern lower-emitting trucks. Also offer incentives for the installation of pollution controls, such as DPF–LNC combinations where low-sulfur diesel is available, or DOCs or flow-through filters where low-sulfur diesel is not available. Also, make cleaner fuels, such as diesel emulsions or low-sulfur diesel, available to off-site trucks. Finally, minimize truck idling by using electrical plug-in devices and automatic idle shutoff devices, and also by enforcing idling limits.

► Repower or replace all **switching locomotives** that do not meet the EPA Tier 0 standards with electric hybrid or alternative-fuel engines. Install engine after-treatments where possible. Require automatic engine-idling controls to minimize unnecessary idling. Finally, commit to using cleaner fuels, such as on-road grade diesel.

Each recommendation discusses the available technology, the pollutants reduced by available technology, the unit cost of the technology, and its cost-effectiveness.

Also, for each recommendation, a discussion of the potential benefits and drawbacks of implementation is included, and, where possible, examples are provided (see "Assumptions Behind Cost-Benefit Discussions, page 18"). Other recommendations discussed include model programs to reduce polluting stormwater runoff at ports and construction design features to control pollution at ports.

MARINE VESSELS

We recommend four major changes to reduce pollution of oceangoing ships and harbor craft: (1) fund the retrofit and repower of existing harbor craft; (2) reduce emissions of oceangoing ships and harbor craft while at berth by providing shoreside power to run necessary systems; (3) reduce emissions by using cleaner fuels in the vessels; and (4) control emissions from oceangoing ships.

Harbor Craft Retrofits and Repowers

Ports should fund an incentive program to encourage tugboat owner/operators to repower and retrofit vessels by replacing older engines with new, lower-emitting engines and then adding after-treatment systems. Upon receiving a cash grant,

CALCULATING COST-EFFECTIVENESS

Calculations used to determine cost-effectiveness are a common tool for evaluating the relative benefits of an emission-reduction strategy. The results are typically given in cost per unit of emissions reduced. For example, $4 per pound of particulate matter (PM) means that the strategy will cost $4 for every pound of particulate matter it reduces over a project's life.

Cost-effectiveness estimates vary significantly depending on the pollutant to be controlled, as well as on the type of source to be controlled. Many measures described here reduce multiple pollutants, a plus on the ground but a complicating factor when comparing cost-effectiveness. Higher levels of emission reductions translate into lower cost-effectiveness per ton of emission reduced; the lower, the better. However, the higher cost-effectiveness of PM reduction strategies must be qualified by the fact that PM is much more toxic than NO_x. Health effects of PM normally occur at concentrations an order of magnitude lower than for NO_x.

There is no single cost-effectiveness threshold that is appropriate for all projects. However, several California rules and programs provide examples. The California Air Resources Board (CARB) has historically adopted rules that cost $5,100 per ton ($2.55 per pound) of NO_x reduced or less and up to $32 per pound of PM reduced. The Carl Moyer heavy-duty diesel vehicle incentive program originally set the minimum cost-effectiveness at $12,000 per annual ton of NO_x reduced. Other Southern California incentive programs set the cost-effectiveness criteria as low as $6,000 per ton of NO_x reduced for on-road projects and $3,000 per ton of NO_x reduced for off-road projects, due to a high degree of competition for incentive funding.

Because new engines are manufactured according to tighter regulations, the marginal benefit of applying pollution reduction measures goes down, as the cost goes up. As a general rule, the lower the cost-effectiveness of a project, the better it is.

Source: California Air Resources Board, *Staff Report: Initial Statement of Reasons, Proposed Diesel Particulate Matter Control Measure for On-Road Heavy-Duty Residential and Commercial Solid Waste Collection Vehicles*, June 6, 2003: 56.

tugboat owner/operators would be required to take their vessels out of service on a specified schedule and install new propulsion engines or after-treatment systems or both. In prioritizing projects, criteria to consider include the emission rates of older engines, the hours the vessel operates, the age of the vessel's engines, the timetable for replacement, and the willingness of the tugboat owner/operator to remain in the same coastal waters after improving the vessel.

Most tugboats use two large diesel engines for main propulsion, along with one or two smaller engines for auxiliary power. Main propulsion engines have useful lives in excess of 20 years; in fact, one survey in the San Francisco Bay area documents many that have been maintained in service for well over 30 years. Older engines, in particular two-stroke engines, tend to be considerably more polluting than new engines available to replace them.

Pollutants Reduced Many existing marine engines can be tuned for higher fuel economy (with higher NO_x emissions) or for lower fuel economy (with lower NO_x emissions). Because no international or national emission standards apply to these older engines, operators have no economic incentive to tune them for low NO_x emissions. While NO_x reductions from tugboat repowering have been well documented, it is likely that PM, VOCs, CO, and CO_2 emissions will be lowered as well because newer engines are generally more fuel efficient. Additionally, engine after-treatments, such as oxidation catalysts, can further reduce PM, VOCs, and CO.

Specific emission reductions will vary by tug, depending on the emissions rate of existing engines, the service provided by the tug and how much it is operated, and the emission rate of replacement engines. Estimates of the annual emissions reduced due to the upgrade of "average" tugs are listed in Table 2-1. Estimates are for tugs of various sizes with two main propulsion engines, and operating 2,000 hours per year. More information on tug emissions can be found in Appendix B.

Addition of an oxidation catalyst would reduce particulates by 25 to 50 percent. Oxidation catalysts also reduce VOCs and CO; typical reductions from on-road vehicles can be as great as 90 percent for both pollutants.

Unit Cost Average prices for replacement engines range from $376,000 to $433,000 per unit.[1] Funding programs usually cover the cost of the new engine only, but labor and dry dock costs can run roughly $200,000. Tug operators usually recoup this extra

TABLE 2-1
Emission Reductions from Tugboat Engine Replacements

Engine Size (Horsepower)	NO_x Emissions Rate (g/bhp-hr)	Annual NO_x Emissions (tons)	Emission Rate for Replacement Engines (g/bhp-hr)	Annual NO_x Emissions from Replacement Engines (tons)	Annual NO_x Emissions Avoided (tons)
1,500–1,999	12.98	129	7.25	67	66
2,000–2,499	14.5	196	7.46	102	94
≥2,500	12.67	446	7.16	252	194

Source: Based on data collected in the San Francisco Bay area.

cost by selling the used engine, at roughly $150,000 for a large engine, and with fuel savings from the improved fuel economy of new engines.[2] Oxidation catalysts cost anywhere from $8 to $10 per horsepower, usually costing more per horsepower for larger units. A tugboat with two 2,000-horsepower engines would cost roughly $50,000 to retrofit with an oxidation catalyst, including the support frames and ductwork necessary for large engines.

Cost-Effectiveness The purchase of replacement engines yields a cost per ton of NO_x avoided between $200 and $600. Cost-effectiveness was not evaluated for oxidation catalysts.

EXAMPLES ▶ There are a number of precedents for successfully repowering tugs with new replacement engines. The majority of the 50 to 60 tugboats in service in the Los Angeles area have been repowered through state and local programs.[3] Tugs have also been repowered in the San Francisco Bay area and in New York Harbor. Hong Kong's Star Ferry has been fitted with an oxidation catalyst, and a retrofit project on New York ferries testing other retrofit technologies, such as selective catalytic reduction (SCR) and diesel particulate filters (DPFs), started in May 2004.[4,5]

DISCUSSION ▶ Replacement programs are relatively simple to administer and can be extremely cost-effective when applied to larger tugs with 2,000 or more hours of operation per year.

Oxidation catalysts are a relatively simple control technology that does not require special maintenance. It is wise to fit vessels with an oxidation catalyst or other after-treatment system while they are already in dry dock for engine replacement. However, it should be noted that operators who install oxidation catalysts will need to use a cleaner grade of marine diesel, with sulfur levels no higher than 500 parts per million.

Tug operators must be persuaded to sign a binding agreement to take their boats out of service temporarily to allow their engines to be replaced. Boats are usually out of service for one month while engines are replaced. Additionally, operators must agree to operate "permanently" in the same coastal waters, in order to ensure that the benefits of the repower remain in the area.

Plugging in to shoreside power should make use of near-zero or zero-emissions technology to provide cleaner power to docked vessels.

Shoreside Power

Marine vessels contribute substantial quantities of air pollution by running onboard diesel auxiliary engines for power while they are at dock. This "hoteling," as it is known, contributes significant but unnecessary pollution, aggravated by auxiliary engines run on bunker fuel—the dirtiest grade of diesel. This measure therefore employs a strategy of hooking docked marine vessels to less polluting power sources and is a critical step to reducing emissions from marine vessels. Plugging in to shoreside power, also known as "cold ironing," should make use of near-zero or zero-emissions technology to provide cleaner power to docked vessels. Several ports throughout the world, including Los Angeles, California; Juneau, Alaska; and

TOM PLENYS

Long cables connect a large container ship to shoreside power.

Göteberg, Sweden, have already implemented shoreside power measures, and they serve as examples.

Specifically, this measure calls for ports to (1) require shoreside power as a condition of new terminal leases or renewals; (2) invest in infrastructure for electric power; (3) develop shoreside power for port-operated facilities; (4) subsidize the development of shoreside power for harborcraft; and (5) provide funding to offset the costs of retrofitting vessels to accommodate shoreside power. For this measure to be successful, sufficient power must be available for use at the wharves. Three specific power source options should be considered: a new installation or an upgraded substation, fuel cell units, and a "power barge."

Installation or upgrade of a port area substation would be appropriate for terminals requiring high power loads, such as cruise terminals or very large cargo areas. Requirements would include 3- to 15-megawatt transformers that meet varying voltage requirements, and flexible connections for vessels loading or off-loading at dock. The emissions associated with the electrical generation supplied by the substation must be significantly lower than the emissions generated by auxiliary engines on the receiving vessels to ensure meaningful reductions, making the use of renewable energy sources or natural gas appropriate. Any port-operated substation should employ the best available control technology (BACT) to reduce pollution impacts.

The second power-generation option is the installation of one or two fuel cell units (200 to 250 kW) at berths where smaller ships (tugboats, commercial fishing boats, and crew/supply boats, for example) are hoteling, and where natural gas is available as a fuel source.

The third option is a power barge equipped with fuel cells that can maneuver within a port to supply power at multiple locations. The fuel cell application might be particularly well suited for cargo ships in berth where diesel generators producing auxiliary loads are in the 1- to 2-megawatt range, as opposed to cruise ships, for which the load can be an order of magnitude higher. Fuel cell technology offers many significant enhancements over existing diesel generators with respect to marine applications. These enhancements include very low exhaust emissions, inherently low vibration and sound levels, and improved thermal efficiency (particularly at low-load levels). The U.S. Navy is one of many navies considering the use of integrated electric plants employing fuel cells in future ship designs. However, ships employing fuel cells for propulsion are not yet commercially available. In fact, fuel cells for auxiliary power or shoreside power generation are also still in the development stage and therefore cannot yet compete with existing technologies on a cost basis. For more information on fuel cells, see Appendix B.

Pollutants Reduced Based on currently available technology for large power applications (greater than 100 kilowatts), emissions from cold ironing would be far below the

TABLE 2-2
Comparison of Emission Rates of Power Generated from Auxiliary Diesel Engines, Conventional Power Plants, and Fuel Cells (lb/MW-hr)

Pollutant	Diesel Fuel[a]	Average U.S. Power Plant[b]	Fuel Cell[c]
NO_x	18.3	3.52	0.002–0.03
CO	25.4	0.33	0.002–0.142
THC	7.6	N/A	N/A
NMHC	N/A	0.04	0.001-0.081

Source: National Fuel Cell Research Center, University of California, Irvine. Power plant data based on the Energy Information Administrations' *Electric Power Industry 2000: The Year in Review* and EPA's *National Emission Trends*.

a Based on naturally aspirated auxiliary diesel engine
b Based on all utility production in 2000 combined, including coal (56 percent), petroleum (2 percent), natural gas (10 percent), nuclear (23 percent), and hydro (8 percent)
c Depends on fuel cell technology employed: PAFC (phosphoric acid fuel cell) or MCFC (molten carbonate fuel cell)

emissions from diesel power generation. The type of fuel used to generate shoreside electricity at a port for either technology approach, of course, will largely determine the level of emissions reductions this strategy will achieve. For cold ironing, the use of more renewables, cleaner fuels, and BACT for power plants in a utility's portfolio will also play a role in overall emissions reductions and will further alleviate concerns about the issue of transferring the pollution problem from the port area to the location of the power generation plant.

The EPA has developed estimates of the current mix of technology used in applications such as auxiliary diesel engines.[6] The range of horsepower ratings for this class of engines is from 50 to 750 hp. Table 2-2 compares current emissions from auxiliary diesel engines to emissions from average U.S. power plants and two different fuel cell technologies. The average power plant in the United States is at least five times as clean as a marine diesel engine.[7] Additionally, notoriously dirty coal-fired power plants alone release only one-third as much NO_x than marine diesel engines.

Unit Cost One major factor inhibiting cold ironing and fuel cell usage for commercial marine applications is its high cost. The price tag for construction of necessary substation(s) along with the transformers, cable, and connectors required to implement cold ironing will vary for different ports. The Princess Tours cruise line spent $2 million to retrofit four cruise ships and an additional $2.5 million on shoreside construction for electrical hookups at its Juneau, Alaska, terminal.[8] The electrical hookups, or "festooning" system, in Juneau had to accommodate 25 feet of tidal variation, winter ice, and severe storms, unlikely events to occur at ports in the lower 48 states.[9] Operating costs of electrical power versus ship fuel used in Juneau are comparable. Although the electrical power there is inexpensive at $0.045 per kilowatt-hour, as more expensive lower-sulfur marine fuel becomes mandatory, higher-priced electrical power in other regions will remain competitive.[10]

Cost-Effectiveness Because this measure has so far been implemented in only two U.S. locations (Alaska and Los Angeles) and because costs are likely to vary